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Flammability of Real Objects: A Progress Report

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Abstract

With United States residential fire statistics as a guideline, this report briefly focuses on the status of research in a few select areas. These include floor coverings, interior wall coverings, and mattresses/bedding. Only in the case of wall coverings are there models which come close to adequately describing real world fire behavior.

1) Which Objects.

There are two relevant questions here: 1) Which objects should fire researchers be concerned with? and 2) Which objects are we able to deal with? It will be evident that there is a disparity between the two classes of objects defined in the context of residential fires in the U. S.

The answer to the first question is suggested by the fire statistics on home fires reported by Miller [1]. The top five objects first ignited in residential fires, in terms of yielding the greatest number of fatalities, are: upholstered furniture, mattresses and bedding, a structural or framing member of a building, interior wall coverings and floor coverings. These account for 55% of U. S. residential fire deaths. On this basis, these would seem to be a natural focus for fire research.

2) Summary of Status

In answering the second question above, the highly varied state of affairs with regard to each is briefly summarized. First, however, it is worthwhile to summarize what it is that fire researchers seek to achieve in addressing the flammability of real objects.

Real objects are, of course, the real problem, as the above summary of fire statistics indicates. Thus the ultimate goal of fire research is the development of means to make each of these classes of objects less hazardous. As a practical matter, this means providing to manufacturers quantitative technical guidelines regarding the relationships between product composition plus configuration and flammability performance in a test relevant to the actual hazard. In general, this requires a balance of empirical testing and modeling as the only realistic way with which to cope with the extreme materials diversity of real products.

With some classes of objects, such as furniture and bedding, the scenario leading to uncontrolled burning is fairly well defined. This makes it possible to significantly reduce such fire occurrences by working to suppress ignitability by the most common sources. In the case of furniture and bedding, this mainly means cigarette ignition; work along these lines has had some success in the past. This is only a first line of defense, however, and real improvements in flammability behavior must come from control of the potential for fire growth on real objects. This fire growth is measured by the rate of heat release from the object in response to some arbitrary but plausible ignition source. Understanding and, ultimately, controlling this rate of heat release response, in turn, requires a quantitative knowledge of the relation between material composition, configuration and fire growth rate. One way to obtain this knowledge is to burn the full-scale object. All too often, this is the only feasible option but it is obviously expensive and the results are scenario dependent. Models are the preferred route around this costly process.

A general modeling approach, adopted with increasing frequency, is one of viewing any burning object as consisting of a large number of area elements, each igniting and releasing heat in response to the incident heat flux imposed by the entire ensemble of burning area elements at any given time. This is in accord with the widespread use of the Cone Calorimeter to characterize heat release rate per unit area as a function of incident heat flux. This device makes it possible to characterize a material (or composite) on a small scale, hopefully obviating the need to build and test each new variant of an object such as a chair covered in a new fabric blend.

This approach is highly attractive and, ultimately, should be quite effective. It will be evident, however, that it has not yet been adequately developed for most real objects.

In turning to the several classes of real objects mentioned above, we begin by dismissing one of these categories as ill-defined, i.e., that of structural or framing member. True structural framing members are normally covered and thus subject to a very limited variety of ignition sources such as electrical shorts or overheated flue pipes. We note that significant work on the safe use of wood heating appliances, including proper practice for passing flue pipes through walls so as to prevent ignition of wooden structural elements, was done some years ago at NIST [2]. This category will not be pursued further here, in the absence of a clearly defined hazard scenario.

Upholstered furniture. Upholstered furniture is the subject of a separate report in this conference [3]. Here we note only that it is both the number one cause of residential fire fatalities and perhaps the most difficult common object for which to predict the fire response because of its geometric complexity and the poorly understood behavior of the thermoplastic materials typical of furniture construction. The goal of a model which can predict the time-dependent heat release rate behavior of real furniture remains elusive, in spite of significant progress in some aspects of the problem in the recent European CBUF study [4].

Flooring materials. According to Hirschler [5], the high level of fatalities in the category in which flooring materials are listed as the first item ignited is misleading. True floor coverings actually account for only one third of the fatalities; accelerants and other items on the floor account for the bulk of the fatalities. Thus flooring materials *per se* are not such a serious threat.

All carpeting sold in the U. S. is subject to a methenamine pill test for flammability which mandates that flame can spread no more than 7.6 cm from this flaming ignition source. Carpeting to be used in corridors of public buildings is usually subject to the Flooring Radiant Panel Test (ASTM E 648) which specifies that the minimum external radiant (as if from a hot gas layer overhead) for flamespread be at least a certain level (e.g., 4.5 kW/m^2). There is some indication that this test is not always an adequate indication of full-scale performance in corridor fire situations [6]. However, recent full-scale tests in rooms also show that burning carpets do not yield a very high rate of heat release (< 75 kW) [7]. Thus the relatively minor activity level in this category of fire hazard seems justified.

Another possible role for carpeting as a fire safety hazard derives from its frequent presence beneath upholstered chairs. Some chairs reach their heat release peak as a result of the interaction between the burning surfaces of the chair and a pool fire which forms on the floor, initiated by flaming drips of molten polyurethane. A carpet is a potentially significant contributor to this type of behavior but no studies of this effect are available.

Interior wall coverings. The flat, vertical surface of a wall has been the logical starting point for most attempts to model fire growth. In recent years a number of models have been proposed, based on a variety of assumptions [8-12]. Their degree of validation against upward spread experiments varies, but all have been applied successfully by their authors to some limited set of circumstances.

A significant aspect of any such attempt to model upward fire spread is the input parameter values. Thus it is not sufficient to pose a model of fire growth *per se* without also specifying the set of experiments and/or procedures which will provide the necessary inputs. This aspect has not received sufficient attention, except perhaps from Delichatsios [13], although his subsidiary measurements include surface temperature, which is difficult to obtain. Furthermore, there has been insufficient attention to the issue of how sensitive the models are to these inputs, and thus how accurately they need to be measured.

Another significant problem for models which use Cone Calorimeter data as a primary input is a procedure for transforming the data from the few constant external heat flux values at which it is obtained to other constant or transient flux values. Mitler [14] proposed a simple procedure which appears to be acceptable for non-charring materials but, in general, it appears that one needs a model of the transient burning process, especially to deal with time-dependent heat input such as would result from interactions with a closed compartment. Delichatsios [11, 13]has proposed such a model.

Another problem which Cone Calorimeter data pose as an input is the choice of the proper external flux for which data are to be used. In general the actual external flux under which the flames are spreading is below that for ignition of the fuel so that special procedures must be used to obtain such data [15,16]. There has been a tendency to choose data from a flux which makes the model agree with experiments rather than to choose a credible value.

Many of these same concerns and difficulties carry over to the case of upward flame spread in a corner wall configuration. Here, Saito [17] has shown that the flow patterns are potentially quite complex and certainly not one dimensional. Hasemi [18] and Kokkala [19] have provided empirical heat flux correlations which can become an integral part of attempts to model this spread configuration. The most prominent attempts thus far [8,20] have been focused on a specific corner test method (ISO 9705) and have not really given much attention to the details of growth in the corner so much as they followed subsequent growth on the ceiling of the room used in this test.

In spite of all the caveats above, it is worth noting that a recent test of three of the above models [8, 9, 10] for flat wall upward flame spread, coupled with a set of procedures for inferring the input data from Cone Calorimeter tests, gave reasonably encouraging results [16, 21]. The materials tested were fiber/resin composites subjected to uniform external radiative heating and a small gas flame igniter at the base. None of the models predicted the results with quantitative accuracy but all were adequate to indicate that the test material was unacceptably flammable. Thus these models may soon be ready to serve the fire safety function of assessing potential fire hazards of interior finish materials.

Mattresses and bedding. The flat, horizontal surface of a bare mattress would also seem to be a logical starting point for fire growth modeling. Rather surprisingly, this has not been the case. An early Federal test requirement (FF 4-72) for cigarette ignition resistance, in effect since 1974 for all mattresses sold in the U. S., may have deflected the attention of fire researchers. The fire statistics above indicate that it did not eliminate the problem.

Atreya [22] developed a model of radial fire growth on a horizontal fuel surface; however, it was applied to wood and required an experimental measure of time-dependent surface temperature as an input. Only recently in the European CBUF study [4] has a model been proposed for growth of a fire on the top surface of a mattress. The CBUF model assumes radial symmetry and a flame spread model essentially the same as that used by Quintiere [8] for upward flame spread. Radiation from the fire plume preheats the remote surface of the mattress. Actual implementation of the model is greatly simplified with extensive empirical fitting to experimental heat release data. There is room for substantial improvement in this type of model.

It must be noted that, as with furniture, the real behavior of a burning mattress is considerably more complex than any model has ever attempted to describe. The most current test methods for mattress flammability testing, California Technical Bulletins 121 and 129, involve strong flaming ignition sources applied to the bottom and the side of the mattress, respectively. Either mode of ignition tends to yield a flame front that involves the full depth of the mattress, not simple surface burning. Furthermore, mattresses can incorporate a complex, layered structure that may include metal springs; these details can, in some cases, make a large difference in the fire behavior [23]. An implication of this is that models cannot be expected to become quantitative prediction tools for designing fire-safe mattresses (or furniture, for that matter). They are tools for clarifying the relative importance of various variables, including those which they may omit. They might become semi-quantitative predictors for limited classes of soft furnishings designs when "calibrated" against full-scale data or they might become a basis for practical correlations between bench-scale and full-scale fire behavior.

Other real objects. If one moves beyond the most common objects implicated by residential fire statistics, one finds examples of much greater complexity with regard to fire behavior. For example, television sets or automobiles. Such objects involve large fractions of thermoplastic materials of arbitrarily complex shape. The specifics of these shapes may play a substantial role in the ease of ignition. Their thermoplastic nature means that they cannot be expected to retain their shape during any fire growth process. A pool fire of polymer melt may interact strongly with the burning mass. There are no models or guidelines for estimating fire growth on such objects. There clearly is a need for systematic study of the burning of at least simple classes of thermoplastic objects. In the meantime testing is likely to be on a very *ad hoc* basis yielding useful data such as total heat release rate which, however, cannot be generalized beyond the specific test configuration.

3) Conclusions

While fire statistics point out a strong need for practical means to make many common objects less flammable, our ability to deal with these in anything other than a very empirical manner is very limited. Only for the simplest geometry (flat, vertical wall) has there been substantial progress in developing models with the potential to generalize the test results from practical, economical small-scale tests on constituent materials. Yet this general approach, the combination of models with empirical inputs which characterize the local response of an element of material to a heat input, still appears to be very promising. Considerable further effort is needed to apply it successfully to most real objects.

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Discussion

James Hoebel: Tom, on the issue of wall coverings: the incident data you showed at the beginning is based on products that are the first item ignited in residential fires and then get the wall covering involved. Are you aware of work going on having to do with the ignition resistance of wall coverings?

Thomas Ohlemiller: Actually, no, I'm not.

Pravinray Gandhi: You mentioned that you are looking into the development of better fire resistant objects. Would that include pillows, bedclothes and fire barriers?

Thomas Ohlemiller: The answer is yes. That's definitely an interesting part of the problem. The bed covers can be used as a very large ignition source to the mattress, for example, and that has to be dealt with. So we'll be looking for that, yes.

John Hall: A couple of observations, Tom. Building on your presentation, in the flooring area, you went directly from flooring to carpeting. And there are a number of other important kinds of flooring and I would particularly cite area rugs as an area worthy of interest. My other observation is that on the interior wall coverings, there is a problem similar to the fuel spill of accelerants for floor coverings and that is a grease build-up.

King-Mon Tu: Among your transparencies, you mentioned that Cone Calorimeter data is very important for this application and you also said that the flux level is very important. Do you have any recommendations on what kind of heat flux level we should use? For example, 25, 25,, 50, 75 or 100 kW/m^2? Is there any justification for this?

Thomas Ohlemiller: The answer is that you have to look at your real problem. You have to put some flux gages into a full-scale test and find out what kind of fluxes are measured. Then you have to realize that some of that is coming from the flame itself and doesn't count as being part of the external flux. You then have to look at the growth problem. The appropriate flux may change, so you may need quite a bit of Cone Calorimeter data, quite a bit of characterization of your material.